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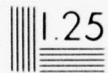
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CEREBRAL ACTIVATION AND THE PLACEMENT OF VISUAL DISPLAYS

Steven M. Casey, William A. Breitmaier, and William E. Nason
Crew Systems Department
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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FINAL REPORT
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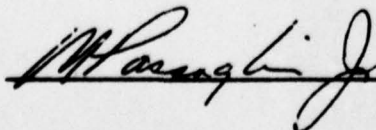
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tracking task. For half of the subjects the engine monitoring displays were presented to the left of the tracking display and for the other half the engine monitoring displays were presented to the right of the tracking display. Performance was found to be better for those subjects who were required to orient to the left than for those who were required to orient to the right. The results of this experiment support the theory that cerebral activation may be an important consideration when locating certain types of visual displays in a high workload cockpit environment.

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I N T R O D U C T I O N

The results of some recent studies of cerebral hemispheric laterality and cerebral activation lend support to the idea that certain types of complex visual displays might be preferentially located to either the left or right side of the human operator. These findings may provide a new basis for organizing and locating visual displays which provide aircraft pilots with important information; information which may be critical to the effectiveness of the man-machine interface. The present study was designed and conducted to determine if these new and previously unapplied findings might be manipulated to enhance the transfer of information between man and machine.

With reference to the design and placement of aircraft displays, the theories of this study provide a basis for speculating that certain types of visual displays should be positioned to the left of the operator as opposed to the right. Likewise, there is reason to believe that other types of displays should be located to the right of the operator as opposed to the left. These predictions are based on known information about (a) the functional asymmetries of the human brain, and (b) the effect of changes in an observer's visual orientation on cerebral activation. Before proceeding, it is necessary to review the research which forms the foundations for the predictions made in this study.

FUNCTIONAL ASYMMETRIES OF THE CEREBRAL HEMISPHERES

The functional asymmetries of the human cerebral hemispheres have been investigated quite extensively in the past century. Most researchers agree that each hemisphere has become somewhat specialized for processing certain types of information. For right-handed individuals, the left hemisphere is clearly dominant in the processing of verbal information (Geschwind, 1972; Kimura, 1973; Studdert-Kennedy, 1970). The dominance of the left hemisphere for verbal processing has been supported by the findings of numerous medical and psychological studies.

In contrast to the primary functions of the left hemisphere, the right hemisphere appears to be specialized for handling information about visual form and "spatial" stimuli. There is evidence that the right hemisphere has an advantage in the perception of melodic pattern, nonspeech sounds, two-dimensional point location, dot and form enumeration, matching of slanted lines, stereoscopic depth perception, and nonvisual location (Carman & Bechtholdt, 1969; Dunford & Kimura 1971; Kimura, 1969, 1973). It has become apparent that the right hemisphere plays a major role in integrating information received by the visual and auditory senses, and more importantly, aids in the formulation of a unified interpretation of that which is perceived.

The cerebral organization of left-handers has been shown to vary somewhat from that of right-handers. Some left-handers show a dominance of the left hemisphere for processing verbal information, while others show a right hemispheric dominance (Bryden, 1965; Goodglass & Barton, 1963;

Montcastle, 1962). Those left handers with a dominant right hemisphere (the hemisphere which primarily processes verbal information) appear to have a family history of left handedness (Zurif & Bryden, 1969). In general, however, the vast majority of the adult population have a left hemisphere which is the dominant processor of verbal information and a right hemisphere which is the dominant processor of spatial-type information (Geschwind, 1972).

CHANGES IN LATERAL ORIENTATION AND ITS EFFECT ON CEREBRAL ACTIVATION

The phenomenon which may enable designers of visual displays to effectively implement the principles of cerebral asymmetries centers around the relationship between shifts in lateral orientation and cerebral activation. At this point it is important to note that this study does not deal with the sensing of images by the left or right visual fields of the eyes. This study does deal with the effect of changes in orientation (looking to the left or looking to the right) on cerebral activation and subsequent human performance.

Both Kinsbourne (1972) and Schwartz (1975) have found that the direction in which an individual is looking can serve as a reliable indicator of the cerebral hemisphere upon which the individual is primarily relying to solve a given mental problem. In their studies, each of these investigators observed subjects who had been instructed to ruminate about various verbal or spatial topics. They found that verbal thought resulted in a preponderance of head and eye movements to the right, and spatial thought resulted in a preponderance of head and eye movements to the left. It appears that a spontaneous shift in orientation to the left may indicate that the right hemisphere is showing some dominance in processing, whereas a spontaneous shift in orientation to the right may indicate that the left hemisphere is dominating in the processing of the information in question.

In contrast to the above studies, other investigations have been conducted to determine the effect of shifts in the direction of orientation on cerebral activation. Under this theory, a deliberate shift in orientation to the left or right (looking to the left of center or looking to the right of center) should activate the right or left hemisphere respectively. This activation of the contralateral hemisphere might facilitate the processing of information which is dominantly processed in that hemisphere. In the first of these studies, Gopher (cited in Kahneman, 1973) found that by having his subjects fixate a point 20 degrees to the right of center, he was able to alter performance on a dichotic listening task which involved verbal stimuli. Looking to the right ostensibly facilitates performance on this type of verbal task by shifting the bulk of cerebral activation to the left hemisphere.

In the second of these studies, Poon, Eisner, and Kinsbourne (1974) found that it was possible to augment human responses to visually-presented information by utilizing the concept of cerebral activation. Performance was facilitated by locating their spatially-analyzed stimuli 90 degrees to the left of their subjects as opposed to 90 degrees to the right.

The most recent study of cerebral laterality and cerebral activation was conducted by Casey (1977). In this investigation, the spatial task involved a comparison of two dot and square diagrams, whereas the verbal stimuli consisted of a comparison of capital and lower-case letters. Twenty-four right-handed male and female students served as subjects. With the subject fixating a point either 20 degrees left of center or 20 degrees right of center, a verbal or spatial display was tachistoscopically projected on the fixation point. The subject was to respond to each presentation by throwing a two-directional switch in the appropriate direction (according to a set of pre-established criteria). Responses to spatial stimuli were significantly faster when the displays were located 20 degrees left as opposed to 20 degrees right. Likewise, responses to verbal stimuli were faster when these displays were located 20 degrees to the right as opposed to 20 degrees to the left, although, this difference was not significant at the .05 level. It should also be pointed out that 19 of the 24 subjects responded faster to the spatial stimuli when they were located 20 degrees left (as opposed to 20 degrees right), and that 18 of the 24 subjects responded faster to the verbal stimuli when they were located 20 degrees right (as opposed to 20 degrees left).

In summary, the theory of cerebral activation through lateral orientation maintains that orienting to the left or right of center will provide the hemisphere contralateral to the direction of the orientation shift with a facilitative input. An orientation shift to the right should thus facilitate left hemispheric processing and an orientation shift to the left should facilitate right hemispheric processing. Therefore, if a given hemisphere is activated with a shift in lateral orientation, the activated hemisphere should be capable of carrying on its processing functions at a greater degree of effectiveness than if the opposite hemisphere were activated. It should follow, then, that a task display which taxes right hemispheric processes might be more effectively positioned to the left of center as opposed to the right, and a task display which taxes left hemispheric processes might be more effectively positioned to the right of center as opposed to the left of center.

THE PRESENT STUDY

In contrast to previous investigations, the present study involved a task setting in which (a) more realistic demands were placed on human operators, and (b) the experimental tasks better approximated those tasks which might be found in a cockpit setting. Of particular interest was the effect that the left or right side placement of a spatial-type peripheral display might have on an operator's performance on a demanding central task.

This investigation involved the use of a central task and a peripherally-located spatial task for two reasons. As stated above, placing a spatial display to the left of center, as opposed to the right of center, has been found to facilitate human responses to the display. In view of this, it was hypothesized that performance on a task with a display located in the center of a control panel - a display directly in front of the operator - might be affected by the left-side or right-side placement of a spatial task display. If a spatial-type display were located to the left of a central

task display, the operator might be able to devote more of his attention to the central task. By locating the spatial display in its "optimum" position (left side as opposed to right side) an operator might be able to maintain a higher level of central task performance. Therefore, in a situation in which a peripheral spatial display is located to the left of a central task display, performance with both central and peripheral tasks might be better than in a situation where the peripheral spatial display is located to the right of the central task display. It was originally hypothesized that performance on a central task display would be facilitated by locating a display for a spatial-type task to the left of the central task display (as opposed to locating the spatial display to the right of the central task display). But, as will be shown below, a different pattern of performance was found than that which was hypothesized.

The second reason for including a central task in this study of central activation had to do with the effects of increased operator demands on peripheral task performance. In the study conducted by Casey (1977), performance differences between left and right-side display location conditions were manifested as differences in reaction times. In the present study it was hypothesized that under conditions of high task demands - one in which an operator must perform a difficult central task in addition to responding to a peripherally-located display - a performance difference might surface in terms of error rates instead of latencies. It was also felt that a more demanding task setting might more accurately ascertain the potential importance of cerebral activation and the placement of certain types of displays.

This study consisted of a comparison of two display panel configuration designs. One design involved a display configuration composed of a centrally-located compensatory tracking task display and an engine monitoring task display which was located to the left of the tracking task display. The other design consisted of a panel configuration composed of a centrally-located compensatory tracking task display and an engine monitoring task display which was located to the right of the tracking task display. The experiment was conducted by the Human Factors Engineering Division of the Crew Systems Department at the Naval Air Development Center. Subjects performed the tasks while seated in the AIDS (Advanced Integrated Display System) fighter-attack cockpit mockup.

M E T H O D

SUBJECTS

Thirty two adult males ranging in age from 19 to 60 years (mean age = 35 years) served as subjects. The subjects were civilian employees and U.S. Navy personnel from the Naval Air Development Center. All were classified as being right-handed from their self reports and by the Crovitz and Zener (1962) test of handedness.

APPARATUS

Each subject performed the tasks in the AIDS fighter-attack cockpit mockup (Figure 1). This entire device was placed inside an Industrial

Acoustics Company model NAR 6L4 acoustic chamber to isolate subjects from extraneous visual and auditory noise. A schematic representation of the entire experimental apparatus can be seen in Figure 2. Outside the chamber, four function generators (Beckman model 9010, HP model 203A, and two HP model 3300A) and a EAI analog computer were used to generate a circular cursor which was displayed on a HP model 120B oscilloscope. The cursor moved in a random fashion across the display. The oscilloscope display was photographed with a COHU electronics television camera and displayed on a Panasonic model TN63 television monitor inside the AIDS cockpit. The television monitor display screen was 3-5/8" in height and 4-7/8" in width. The task involved keeping a 3/16", white circular cursor inside the boundaries of a stationary 5/8" black circle in the center of the screen. As the cursor moved across the display compensatory adjustments had to be made using a 1-1/4" joy stick located directly in front of the tracking display. The operator's input, via the joy stick, was reflected as a compensatory movement on his display screen. Joy stick control movements were channeled to the analog computer, integrated into the cursor signal output, and displayed on the oscilloscope, and hence, the television monitor inside the cockpit. Integrated tracking error was displayed on a Berkeley model 554 EPUT meter for hand recording by one of the experimenters.

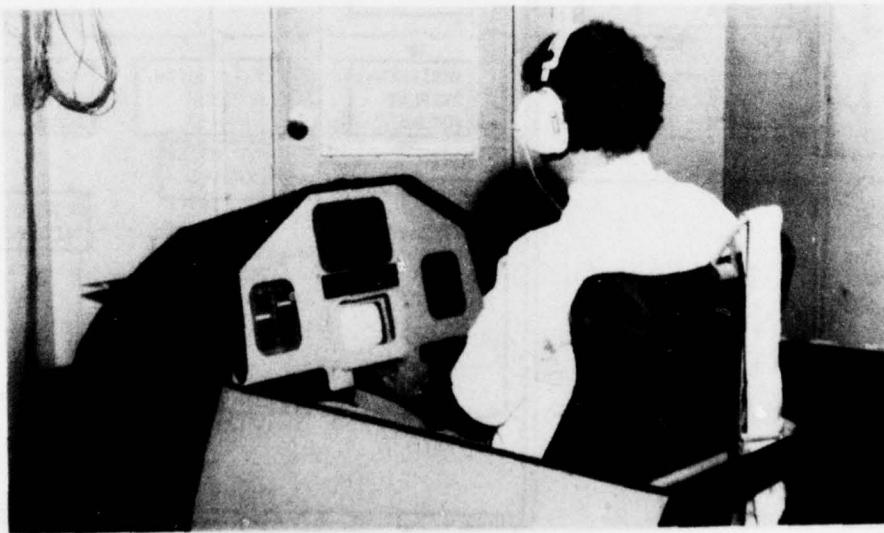


FIGURE 1. The AIDS fighter-attack cockpit mockup.

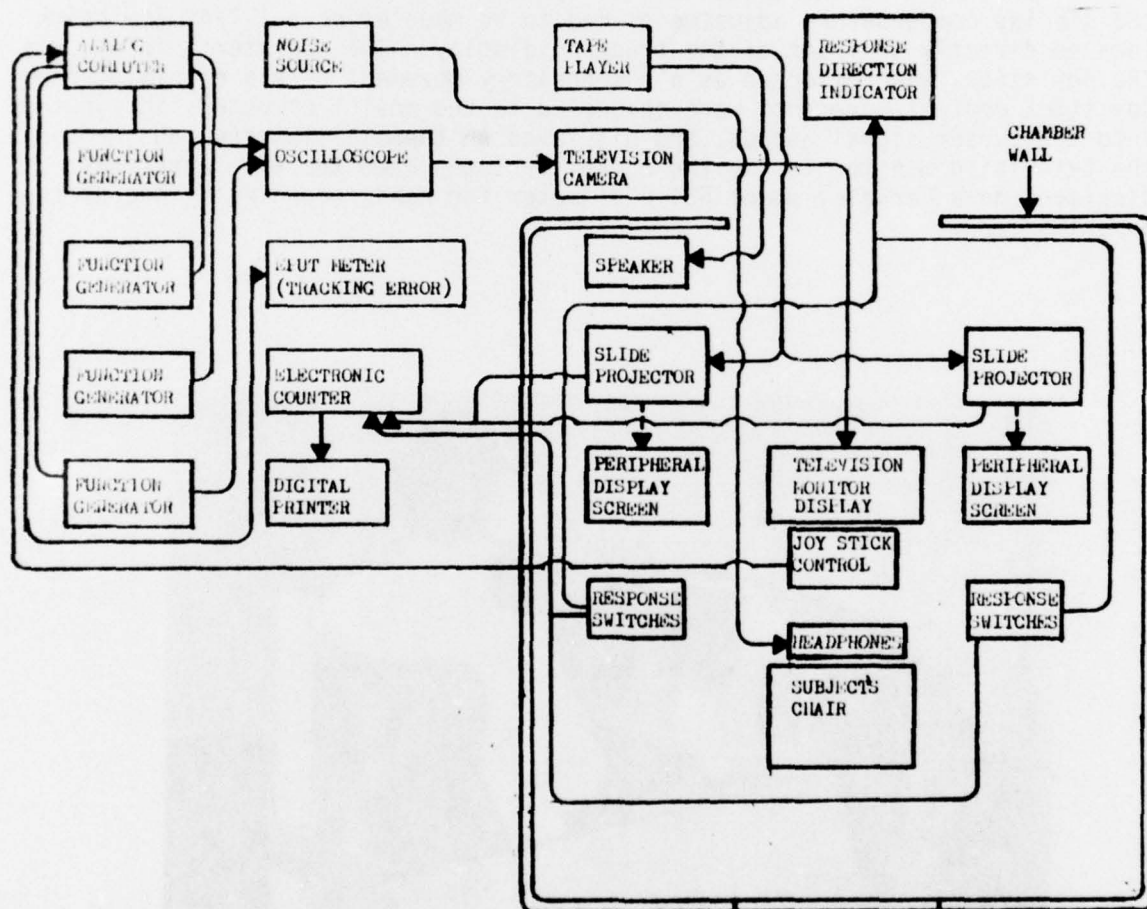


FIGURE 2 - Schematic drawing of the experimental apparatus.

The peripherally-located engine monitoring displays were rear-projected onto a display screen located either to the left or right of the central tracking display. Each screen was 4" in width and 5-1/2" in height. The inside edge of each of these peripheral display windows was 6-1/2" from the center of the cockpit display panel. When seated in the cockpit, the average distance between the subject's eyes and the center of the cockpit display panel was 26", resulting in a visual angle of 14 degrees to the inside of each peripheral display (as measured laterally from the center of the tracking display screen), an 18 degree angle to the center of each peripheral display screen, and a 22 degree angle to the outside edge of each peripheral display screen. For each subject, the engine displays were only projected on the left-side screen or the right-side screen. At no time was the display on the other side used. These peripheral engine monitoring displays were projected with a Kodak Autofocus slide projector. A green filter was used to color the peripheral displays to approximate the appearance of a CRT display.

Two peripheral-task response switches were mounted 1-1/2" apart on either the left or right-side console of the cockpit. An illuminated blue button was positioned between the two response switches. Responses were made only with the index finger which was kept on the blue button when no response was required. This entire peripheral-task response mechanism could be mounted in the left-side console or the right-side console. The two response switches were connected to two indicator lights located at one of the experimenters' stations outside the chamber allowing the experimenter to see which response button had been activated. A HP model 5248L electronic counter was connected to a photocell attached to the lens of the slide projector and the two peripheral task response switches. Reaction times were automatically printed by a HP model 5628 digital printer.

A Rudmose diagnostic audiometer served as a source for generating 82db(A) of broad band white noise over a set of earphones. This masked the cuing noises of the slide projector.

PERIPHERAL TASK DISPLAY

A peripheral task display was developed in accordance with (a) the known biases of the right hemisphere, and (b) the design characteristics of a proposed computer-generated engine display. As stated above, the right hemisphere may have an advantage in two dimensional point location, a finding which served as a basis for the selection of the peripheral task display. One possible outcome of the current AIDS development project is an aircraft display which will present the pilot with a summary of all engine performance parameters. The over-all efficiency level at which each engine is performing is designated by a floating arrow - with efficiency levels ranging from 0 to 110 percent. Two arrows move up and down vertical columns and indicate to the pilot the level of each engine's performance. A variation of this approach was developed into the peripheral task displays because it was felt that the process of making a judgment about the position of these arrows along a single dimension would tax right hemispheric processes, thus resulting in a performance advantage when projected on the left display screen as opposed to the right.

When each peripheral display was presented, the subject had to make a response indicating whether the display represented an "acceptable" or "unacceptable" engine efficiency condition. The three displays in Figure 3 are examples of the classes of displays to which the subjects were to respond "acceptable." An acceptable condition was one in which (a) the "engine 1" arrow was in the 65 to 80 region and the "engine 2" arrow was in the 100 to 110 region, (b) both arrows were in the 80 to 100 region, and (c) the "engine 1" arrow was in the 100 to 110 region and the "engine 2" arrow was in the 65 to 80 region. All other arrow arrangements were classified as being "unacceptable." Example "unacceptable" displays can be seen in Figure 4. Half of the displays presented to each subject were "acceptable" and half were "unacceptable." These response criteria were developed solely to meet the requirements of the experimental task and do not necessarily represent proper responses to a cockpit display of this type.

PROCEDURE

Each subject was randomly assigned to a condition in which he performed the central and peripheral tasks in either cockpit "A" (Figure 5) or cockpit "B" (Figure 6). For both designs "A" and "B" the tracking task was located in the center display window. In cockpit "A" the engine efficiency displays were presented in the left-side display window, and in cockpit "B" the engine efficiency displays were presented in the right-side display window. Sixteen subjects performed in the cockpit "A" configuration and 16 subjects performed in the cockpit "B" configuration.

To convert a cockpit "A" configuration to a cockpit "B" configuration and vice versa, the slide projector, green filter, and photocell were moved from behind the left panel display and repositioned behind the right panel display. The unused display window was illuminated from the rear to produce a level of brightness approximately equal to the level of brightness on the display in use (when no stimulus was being presented).

Upon entering the laboratory, the subject was requested to sign a participation consent form and to fill out the Crovitz and Zener (1962) handedness questionnaire (Appendix A). Once seated in the cockpit, the subject was told that he would be performing two separate tasks and would be responding with a different hand for each task. Eight of the sixteen subjects who performed in cockpit "A" were required to operate the joy stick with their right hand and respond to the peripheral engine displays using only the index finger of their left hand. In this case, the engine efficiency task response switches were mounted on the left side console. Likewise, 8 of the 16 subjects who performed in cockpit "A" were required to operate the joy stick with their left hand and respond to the peripheral displays using only the index finger of their right hand, in which case the engine efficiency task response switches were mounted on the right console. The same hand of response balancing procedure was implemented for the 16 subjects performing in cockpit "B". The hand of response was balanced in this investigation due to the importance of this variable in studies of cerebral laterality (Simon, Henrichs, & Craft, 1970). Additionally, confounding effects due to control-display relationships would thus be eliminated.

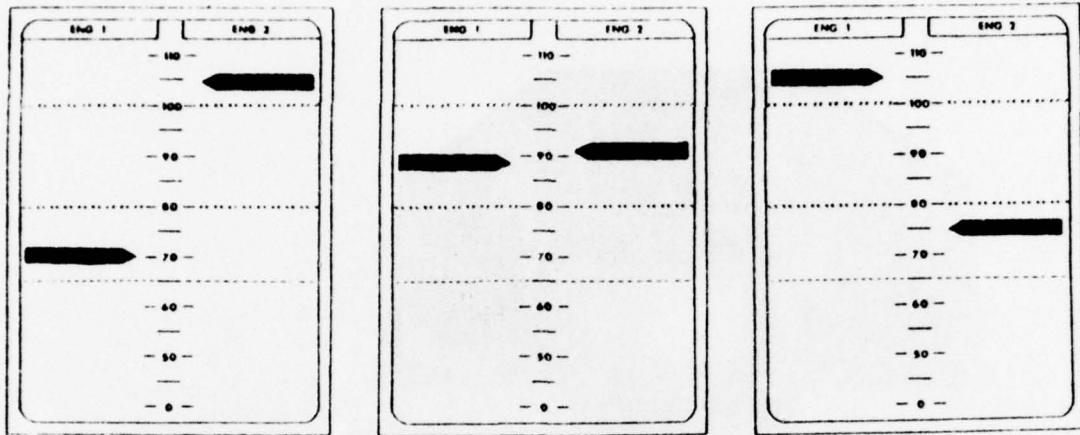


FIGURE 3 - Example engine efficiency displays from each of the three classes of "acceptable" conditions.

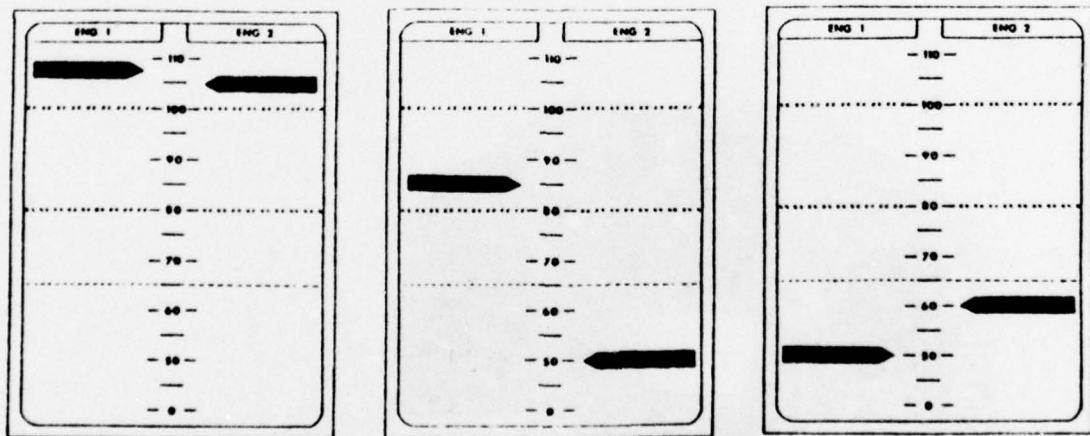


FIGURE 4 - Three examples of engine efficiency displays which present "unacceptable" conditions.

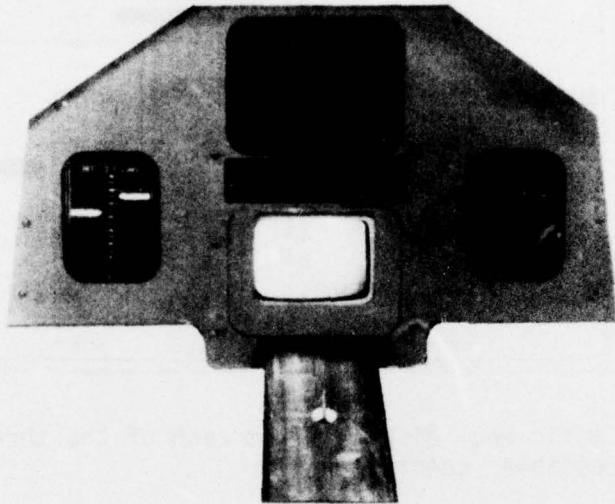


FIGURE 5 - Display configuration "A".

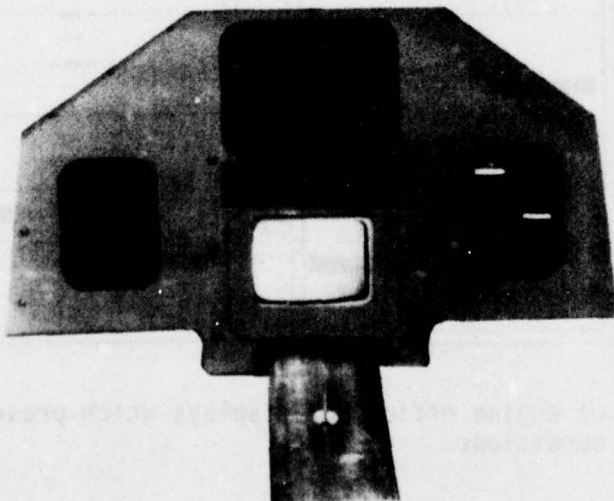


FIGURE 6 - Display configuration "B".

After a brief verbal summary of the tasks, the subject received a set of pre-recorded instructions (Appendix B). The tape player automatically changed the example stimulus displays to coincide with the recorded verbal instructions. At the end of the instructional period, white noise was produced through the earphones and the lights inside the chamber were turned off. The rear window of the chamber was left unoccluded so the subject could be observed while performing the task. The subject then performed during a series of practice sessions. Since a pilot study indicated that an asymptotic level of performance was reached after approximately 10 minutes of training on each task, each subject performed for five two-minute practice blocks with 20 seconds of rest between each block. During these two-minute sessions the subject had to continuously track the moving cursor on the tracking task display, attempting to keep it inside the stationary black circle in the center of the screen. During each two-minute performance block, eight engine efficiency displays appeared on the designated peripheral screen, each for a duration of 700 msec. The interstimulus interval varied randomly between 4 and 28 seconds. The subject could therefore not predict when the display might appear. However, the engine efficiency display darkened 800 msec prior to its onset thus cuing the subject to orient to the display for the presentation of the peripheral stimulus.

The subject was told that when an engine efficiency display appeared on the screen he had to determine if the engine condition was "acceptable" or "unacceptable" and to respond by touching the appropriate switch. Therefore, when an engine efficiency display appeared on the peripheral display screen, the subject had to stop attending to the central task momentarily, attend to the peripheral display screen, make a decision and a response, and quickly shift his attention back to the central tracking task display.

After the practice session each subject performed the tasks for four 7-1/2 minute test sessions. Each 7-1/2 minute test session was separated with 30 seconds of rest, during which time the slide tray was changed on the projector. A total of 30 peripheral task displays were presented during each 7-1/2 minute period with an interstimulus interval varying randomly between 4 and 28 seconds. Each subject was thus required to respond to a total of 40 peripheral displays in the training session and 120 peripheral displays in the test session.

RESULTS

The dependent variables were integrated tracking error on the central task and percent correct responses on the peripheral task.* Performance on each task for cockpit "A" was compared to the performance on each task for cockpit "B". Although performance was monitored during both the training and test trials, all analyses to be discussed were comparisons of performance on the test trials only.

*As stated previously, reaction times for the peripheral task were recorded. However, there was some question as to the accuracy and reliability of the timing mechanisms which resulted in the elimination of the reaction times as a dependent variable.

PERIPHERAL ENGINE EFFICIENCY TASK

A test of the differences in variability of the peripheral task accuracy scores indicated that the distribution of cockpit "B" accuracy scores had a significantly larger variance than the accuracy scores from cockpit "A" ($p < .05$). Due to the significantly different distribution of these two groups of scores, a nonparametric test was conducted to determine if the average performance levels for these two groups were significantly different. The Kruskal-Wallis H test for ranks, a nonparametric analog of the ANOVA of means, indicated that the accuracy scores for the two groups were not significantly different at the .05 level. However, there was a strong trend for peripheral task accuracy scores on cockpit "A" to be better (higher) than peripheral accuracy scores on cockpit "B" (Figure 7).

CENTRAL TRACKING TASK

Unlike the peripheral task scores, there were no significant differences between the variances of the two tracking error scores of cockpit "A" and cockpit "B". A t test was thus conducted on this data. Although there was a strong trend for the cockpit "B" tracking error scores to be better (lower) than the cockpit "A" tracking error scores, they were not significantly different at the .05 level. These results are illustrated in Figure 8.

COMBINED "LEFT" VERSUS "RIGHT" SCORES

Because of the strong performance trends evident in the central and peripheral task performance measures, an additional statistical test was conducted which sought to assess the effects of display location on performance. Although not significantly different, peripheral task accuracy was better when the display was presented on the left side of the panel (cockpit "A") as opposed to the right side of the panel (cockpit "B"). Central task performance tended to be better in cockpit "B" than in cockpit "A". *Therefore, it appears that subjects tended to emphasize the display (regardless of whether it was the central display or the peripheral display) which was to the left of the other display.* Cockpit "A" appeared to result in subjects emphasizing the peripheral display, and cockpit "B" appeared to result in subjects emphasizing the central display. A common trend thus surfaces between the two groups of subjects; the display which was farthest to the left (the peripheral display in cockpit "A" and the central display in cockpit "B") appeared to be emphasized over the display which was farthest to the right. An analysis was thus conducted to explain the behavior of the subjects in each experimental group.

Essentially, the task performance for the displays located farthest to the left (cockpit "A" peripheral display and cockpit "B" central display) had to be compared to performance on the displays located farthest to the right (cockpit "A" central display and cockpit "B" peripheral display). First, all peripheral task scores for the 32 subjects were converted to z scores. The same was done for the 32 central task scores. Two groups of scores were thus constructed - one consisted of the 16 z scores from the cockpit "A" peripheral task and the 16 z scores from the cockpit "B" central task. This provided 32 scores for the task display which was always to the left of the

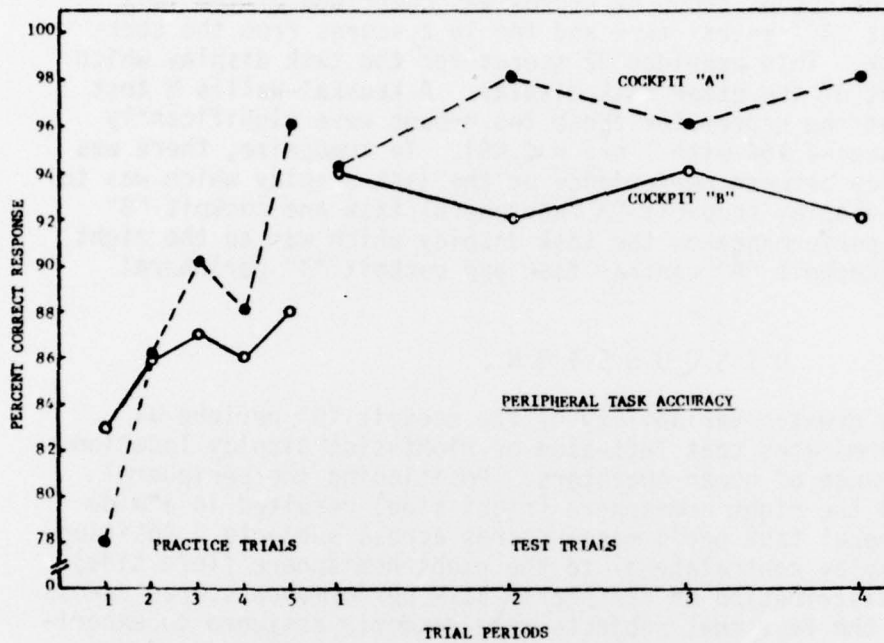


FIGURE 7 - The effect of peripheral task display location on peripheral task accuracy.

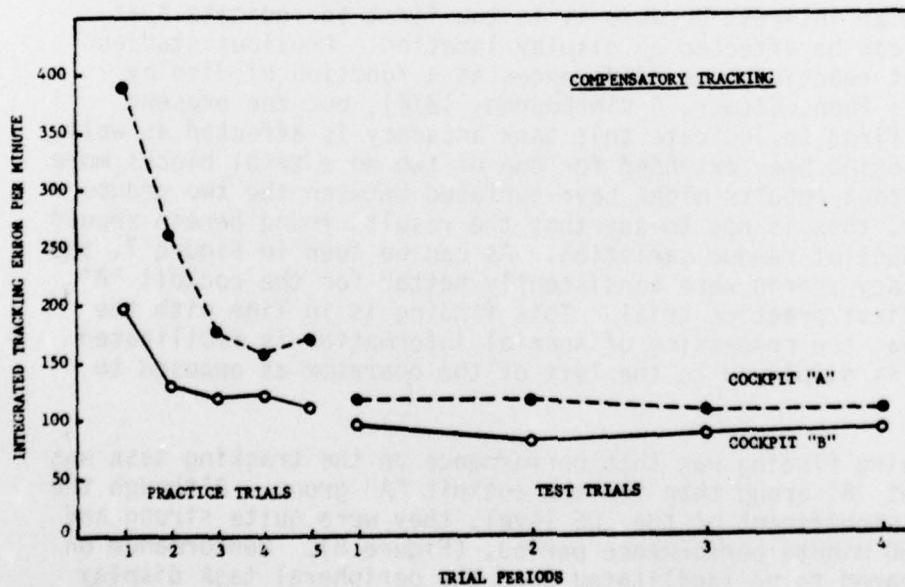


FIGURE 8 - The effect of peripheral task display location on tracking performance.

other task display. The second group of scores was comprised of the 16 \bar{z} scores from the cockpit "A" central task and the 16 \bar{z} scores from the cockpit "B" peripheral task. This provided 32 scores for the task display which was always to the right of the other task display. A Kruskal-Wallis H test of ranks indicated that the scores for these two groups were significantly different (H (chi square)=4.164 with 1 df, $p < .05$). To summarize, there was a significant difference between performance on the task display which was to the left of the other display (cockpit "A" peripheral task and cockpit "B" central task) and the performance on the task display which was to the right of the other display (cockpit "A" central task and cockpit "B" peripheral task).

DISCUSSION

The significantly greater variability of the cockpit "B" peripheral task accuracy scores indicates that left-side or right-side display location influences the performance of human operators. Positioning the peripheral display ipsilateral to the right hemisphere (right side) resulted in a wide distribution of peripheral task performance scores across subjects. Positioning the peripheral display contralateral to the right hemisphere (left side) resulted in a narrow distribution of peripheral task performance scores across subjects. In view of the fact that subjects were randomly assigned to experimental conditions, there is no reason to suspect that the two groups of subjects differed in their basic task abilities. The varying distributions of performance scores can therefore be explained by the influence of lateral orientation and cerebral activation on visual information processing.

The strong trend toward better peripheral task performance in the cockpit "A" condition also provides support to the initial hypothesis. This finding is of particular interest because it is the first to indicate that performance accuracy can be affected by display location. Previous studies have found significant reaction time differences as a function of display location (Casey, 1977; Poon, Eisner, & Kinsbourne, 1974), but the present investigation is the first to indicate that task accuracy is affected as well. Had the performance period been extended for one or two more trial blocks more statistically significant results might have surfaced between the two groups of subjects. However, this is not to say that the results found herein should be viewed as the product of random variation. As can be seen in Figure 7, the peripheral task accuracy scores were consistently better for the cockpit "A" condition after the first practice trial. This finding is in line with the initial prediction that the processing of spatial information is facilitated when the information is displayed to the left of the operator as opposed to the right.

The most surprising finding was that performance on the tracking task was better for the cockpit "B" group than for the cockpit "A" group. Although the differences were not significant at the .05 level, they were quite strong and consistent over the 30 minute performance period, (Figure 8). Performance on the central task appeared to be facilitated when the peripheral task display was located to the right of the central task display-as opposed to the left. This result was totally opposite to the initial prediction of the effect of peripheral display location on central task performance. It was originally

felt that central task performance would be improved by placing the peripheral task to the left of the central tracking task display-as opposed to the right. If subjects could make faster responses to the peripheral task when it was displayed to the left-as opposed to the right-(while maintaining an equal or better level of accuracy), they might have been able to devote more time and effort to the central task. In contrast to this prediction, central task performance was poorer in the cockpit "A" condition than in the cockpit "B" condition. Subjects performed better on the display which was farthest to the left as opposed to the display which was farthest to the right. Peripheral task performance was better in cockpit "A" and central tracking task performance was better in cockpit "B".

The combined score, which compared the performance on the task which was farthest to the left with performance on the task which was farthest to the right, may appear to be a rather odd comparison. However, the results of this analysis convey valuable information concerning relative display location and task performance. In view of (a) the better central task performance with cockpit "B" and (b) a retrospective reevaluation of the central tracking task display, it was felt that the central tracking display may also have taxed right hemispheric processes. Two dimensional dot location has been shown to have a right hemispheric advantage (Kimura, 1973). It might be logical to assume that when either of these displays was located to the left of the operator that task performance would have been facilitated. However, in the present case, the location of the central tracking display did not differ between the cockpit "A" and cockpit "B" configurations. It becomes apparent that moving the peripheral display from the left side to the right side (and vice versa) somehow influenced central task performance as well as peripheral task performance.

Two interpretations can be provided as possible explanations for the outcome of the combined "left" versus "right" analysis. In both cases the assumption is made that the central display and the peripheral display taxed right hemispheric processes. The first interpretation is that, although each subject was told not to lean to one side while performing the tasks, subjects may have positioned themselves between the two displays. In cockpit "B", for example, a subject who had situated himself between the two displays would have oriented to the left to view the tracking display and oriented to the right to view the engine monitoring display. This would explain the relatively superior performance on the tracking task for the cockpit "B" condition. Subjects performing in the cockpit "A" condition would have been orienting to the left to view the engine monitoring display and orienting to the right to view the tracking display. Relatively superior performance would thus be expected on the engine monitoring display in cockpit "A". At no time did any subject indicate that he adapted this orienting technique, nor was any subject observed who positioned himself between the two displays.

The second interpretation is seen as being more plausible. The relationship between lateral orientation and cerebral activation can be considered as a process which operates on the relative position of displays rather than on their absolute location. Right hemispheric processing may be: (a) facilitated by orientation to the left, (b) disrupted by orientation to the right, and (c) unaffected when orientation is straight ahead. In a situation in which one

spatial display is located to the left and a second is located centrally, an operator may place emphasis on the spatial display which is farthest to the left, allowing him to take full advantage of his right hemisphere's processing abilities. Furthermore, when presented with a centrally-located spatial display and a right-side peripheral spatial display, an operator may place emphasis on the central display because it allows him to more easily utilize his right hemisphere's processing abilities. Operators may seek to optimize responses to the display which is "the most" contralateral to the hemisphere which dominates in processing the displayed information.

The significant result of the combined "left" versus "right" analysis is particularly interesting in view of the strong though not statistically significant results of the analysis of the two individual task performances. The combined analysis was, in effect, a within subjects analysis, which contrasted subjects' relative performance on the task display farthest to the left to relative performance on the task display farthest to the right. It is recommended that future studies of cerebral activation and display placement utilize within subjects designs. The effect of various design alternatives on individual performance may then be more accurately assessed.

COMMENT

These results present an interesting trade-off which may be of critical importance when positioning displays in a high workload cockpit environment. Specifically, the findings indicate that the relative locations of displays with one another are as important as display location alone. Introducing an additional display and task into this study of cerebral activation has raised some important issues concerning the application of this theory to the design of aircraft displays. Obviously, a designer would not want to sacrifice performance on a critical centrally-located task display by positioning a less critical task display on the left side of the control panel. At the same time, there may be more important reasons for locating a display of high importance in the center of the display panel - directly in front of the operator. The importance of pilot display-location expectancies and the need to have certain flight information situated directly in front of the operator may be much greater than the potential effects of cerebral activation and subsequent pilot performance.

On the other hand, the available information on cerebral activation and task criticality can be combined to produce a more efficient cockpit display configuration. For example, certain information is continuously required by the pilot (such as aircraft attitude, heading, and speed) and should therefore be positioned centrally within a 30° cone of vision consistent with present pilot expectancies and design principles. However, situationally required information, that which is automatically presented to the pilot during appropriate situations, would be displayed graphically to the left of the pilot. Situationally required information might graphically indicate the presence of a collision hazard, the location of the hazard, and the proper action to avoid the hazard. Warnings of system failure, malfunctions, and the locus of potential problems would also be automatically displayed at the appropriate times. When displayed, this information demands the full and immediate attention of the pilot and would be most advantageously located on the left side of the display panel. Other non-critical information could be

displayed on the right-side control panel and would require an input initiated by the pilot. Various checklists, noncritical performance information, navigation information, and avionics information might be graphically or alphanumerically displayed to the right of the pilot. This general arrangement concept is still hypothetical and requires further study.

Additional investigations are obviously needed to gain a further understanding of the types of displays which might require preferential placement in the cockpit environment. The available evidence has demonstrated that both reaction time and accuracy are affected by the location of certain task displays. Cerebral activation can thus be viewed as a topic which designers must contend with when organizing and positioning visual displays. This will be particularly true with reference to the design of computer generated displays. The ground rules are now being laid for designs entering production 10 and 20 years in the future. Every effort should be made to incorporate the natural capabilities and limitations of the human element of the system into the design of visual displays. The present study has indicated that cerebral activation may play a larger role in human information processing than was previously suspected, indicating that response accuracy as well as reaction time is affected by the location of certain types of displays. The importance of the concept has the greatest consequence in high workload settings such as in a V/STOL cockpit environment. Investigations should now be conducted to uncover other possible characteristics of the phenomenon and to determine the applicability of this principle to the AIDs program.

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A P P E N D I C E S

APPENDIX A. Test for Handedness

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TEST FOR HANDEDNESS

NAME _____

ANSWER THE FOLLOWING QUESTIONS CAREFULLY. IMAGINE YOURSELF PERFORMING THE ACTIVITY DESCRIBED BEFORE ANSWERING EACH QUESTION. ANSWER BY DRAWING A CIRCLE AROUND THE APPROPRIATE SET OF LETTERS APPEARING TO THE LEFT OF EACH QUESTION WHOSE MEANINGS IS:

Ra = right hand always.

Lm = left hand most of the time.

Rm = right hand most of the time.

La = left hand always.

E = both hands equally often.

X = do not know which hand.

-
- (1) Ra Rm E Lm La X: is used to write with.
 - (2) Ra Rm E Lm La X: to hold nail when hammering.
 - (3) Ra Rm E Lm La X: to throw a ball.
 - (4) Ra Rm E Lm La X: to hold bottle when removing top.
 - (5) Ra Rm E Lm La X: is used to draw with.
 - (6) Ra Rm E Lm La X: to hold potato when peeling.
 - (7) Ra Rm E Lm La X: to hold pitcher when pouring out of it.
 - (8) Ra Rm E Lm La X: to hold scissors when cutting.
 - (9) Ra Rm E Lm La X: to hold knife when cutting food.
 - (10) Ra Rm E Lm La X: to hold needle when threading.
 - (11) Ra Rm E Lm La X: to hold drinking glass when drinking.
 - (12) Ra Rm E Lm La X: to hold tooth brush when brushing teeth.
 - (13) Ra Rm E Lm La X: to hold dish when wiping.
 - (14) Ra Rm E Lm La X: holds tennis racket when playing.
- Do you consider yourself to be right handed, left handed, or neither?
-

(Every item is scored on a 5-point scale. On items 1, 3, 5, 7, 8, 9, 11, 12, and 14, Ra is scored "1"; Rm, "2"; E, "3"; Lm, "4"; and La, "5". All other items (2, 4, 6, 10, 13) are scored in the reverse fashion. Items marked X are prorated. The highest possible right-handed score is 14, and the highest left-handed score is 70.)

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APPENDIX B. Subject Instructions

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SUBJECT INSTRUCTIONS

As stated before, you will be performing two separate tasks during this experimental session. The first task, which is referred to as the central task, involves the video screen directly in front of you. The small white circle on the screen will travel in a random fashion over the entire display. Your job is to keep the moving circle within the boundaries of the black circle in the center of the screen - or as close to it as possible using the control stick directly in front of you. If you have not already done so, grasp the control stick and try to keep the moving circle within the black circle. While doing this, keep in mind that your performance on this task will be measured as a function of how close you are to the center of the screen. The farther the moving circle travels from the center, the worse your score. Your performance will be measured continuously throughout the entire session. Therefore, it is important that you perform this task to the best of your ability.

At random points throughout the performance period you will be presented another display on this screen.* This display involves a hypothetical situation in which the efficiency of each aircraft engine must be monitored.* You will have to determine if the over-all engine efficiency is acceptable or unacceptable. If you will look at the display, you will notice that the screen is broken up into four basic sections - there being a horizontal line at 65, 80, and 100. Each arrow will fall within one of these four regions. Basically, there are three conditions in which the engine efficiency is called acceptable. The first* is where each pointer lies within the 80 to 100 region. The second* is when the left arrow lies in the top region and the right arrow lies in the 65 to 80 region. The third display which is classified as acceptable looks like this*. The left arrow is in the 65 to 80 region and the right arrow is in the top region.

It is important to remember that the arrows may point to any number within a region. It is the region in which the arrows lie, and not the number to which each arrow is pointing, which is important.*

To review, there are only three displays which can be called acceptable.* A display in which both arrows lie within the 80 to 100 region;* a display in which the Engine 1 arrow lies within the 65 to 80 region and the Engine 2 arrow lies within the 100 to 110 region; and * a display in which the Engine 1 arrow lies within the 100 to 110 region and the Engine 2 arrow lies within the 65 to 80 region.*

An unacceptable condition is one where the arrows do not fall in the above categories. If both arrows are in the top region* the condition is unacceptable. If both arrows fall within the 65 to 80 region*, the

* Indicates the presentation of a display on the appropriate peripheral display screen.

condition is unacceptable. If at any time either arrow falls in the bottom region, 0 to 65, the condition is unacceptable. For example, this is unacceptable*, this is unacceptable*, and this* is unacceptable. As a few more examples,* this is unacceptable because one arrow is in the upper region and the other is in the 80 to 100 region. Similarly, this* is an unacceptable condition.

To repeat the acceptable conditions;

- * this is an acceptable condition
- * this is an acceptable condition
- * and this is an acceptable condition

All others will be unacceptable.

These engine displays will be presented at random points while you are performing the central tracking task. When an engine display appears on the screen, look at the display, make your decision and respond by pushing the appropriate button - acceptable or unacceptable. At all other times keep your response finger on the blue light. Make your response as quickly and as accurately as you can, return your finger to the blue light, and continue performing the central tracking task. You should try to perform each task to the best of your ability.

It is important that you remain seated in an upright position and do not lean to one side or the other. Also, continue to respond to each task only with the appropriate hand.